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A SIMPLE WIDE-FIELD CASSEGRAIN TELESCOPE

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SUMMARY

A telescope giving an extended flat field of good imagery can be achieved by adding to a paraboloidal prime mirror a spherical convex secondary mirror and a nearly afocal spherical surfaced close doublet lens. Data are given for two designs covering an angular field of 1·5° diameter at a relative aperture of f/8.

1. INTRODUCTION

In a Cassegrain telescope the field angle of good resolution is severely limited by aberrations; a variety of experients have been adopted to give larger field sizes. The Ritchey–Chrétien form of telescope, giving a secondary focus image free from spherical aberration and coma, has been adopted for several telescopes over the past decade. At a focal ratio of around *f*/8 these give much larger useful field sizes than Cassegrain telescopes, but their uncorrected astigmatism and field curvature limit the field, typically to about ± 9 arcmin for a flat image surface and an image spread within about 0·5 arcsec (Wynne 1968), and the fact that the prime mirror is not paraboloidal may have disadvantages for other uses of the telescope. The addition of an aspheric plate behind a modified Ritchey–Chrétien mirror pair can give excellent imaging over much larger fields; for example, a telescope of 1-m aperture with a field of ± 1·4° has been described by Bowen & Vaughan (1973). With such an extended field as this, the provision of masks to prevent direct star light from reaching the focal plane presents some problems. These are admirable special purpose wide-field telescopes, but the design does not lend itself readily to use at different focal stations.

There may therefore be some interest in designs of extended field two mirror telescopes that employ a paraboloidal prime mirror.

Such systems, employing a nearly afocal spherical surfaced doublet lens corrector behind the mirror pair, have been discussed by Wynne (1973). It is shown that for a true Cassegrain mirror pair, the required aberration correction is not possible with a doublet lens, but this becomes possible with suitable modifications to the secondary mirror, which may take the form either of using a secondary with a different asphericity from the true Cassegrain, or of moving the Cassegrain secondary further away from the prime, so that it and the prime mirror no longer have a common geometrical focus. The latter system is being adopted for use on the 3·6-m Canada–France–Hawaii telescope. For small-field observations, such a system would be used without the doublet as a true Cassegrain; for wider field work the secondary mirror would be displaced axially, and the corrector inserted. The distance of the secondary focus behind the prime mirror is necessarily different in the two configurations.

Wynne's paper—discussed above—was concerned with secondary focus extended field systems for large telescopes, for which the angular field size that can conveniently be used is limited by the size of photographic plate to some 30–50 arcmin diameter. This paper is concerned with wider field systems suitable for smaller telescopes.

TABLE I

1-*m f*/4·85 *paraboloid with spherical secondary and doublet lens corrector: design* 1

Radius (cm)	Axial separation (cm)	Material	Clear diameter (cm)
−970·87* (mirror)			100
	−290·78	air	
−990·10 (mirror)			47·8
	188·52	air	
−329·62			32·2
	1·55	UBK7	
−150·52			32·2
	0	air	
70·24			31·8
	1·00	UBK7	
55·11			31·4
	131·06 to focal plane	air	

Notes:

* Axial radius of paraboloid.
Corrected for flat field of ±0·75°, for spectral range 365–852 nm.
Distortion ratio at edge of field 1·0027 (pincushion).
Equivalent focal length 806·48.
A surface of positive radius is convex toward the sky, a negative one is concave.

TABLE II

1-*m f*/4·85 *paraboloid with spherical secondary and doublet lens corrector: design* 2

Radius (cm)	Axial separation (cm)	Material	Clear diameter (cm)
−970·87* (mirror)			100
	−290·78	air	
−990·10 (mirror)			47·8
	183·99	air	
70·29			32·4
	4·626	UBK7	
55·71			31·3
	3·372	air	
−108·53			31·3
	1·374	UBK7	
−82·25			31·3
	129·51 to focal plane	air	

Notes:

* Axial radius of paraboloid.
Corrected for flat field of ±0·75°, for spectral range 365–852 nm.
Distortion ratio at edge of field 1·0027 (pincushion).
Equivalent focal length 810·40.
A surface of positive radius is convex toward the sky, a negative one is concave.

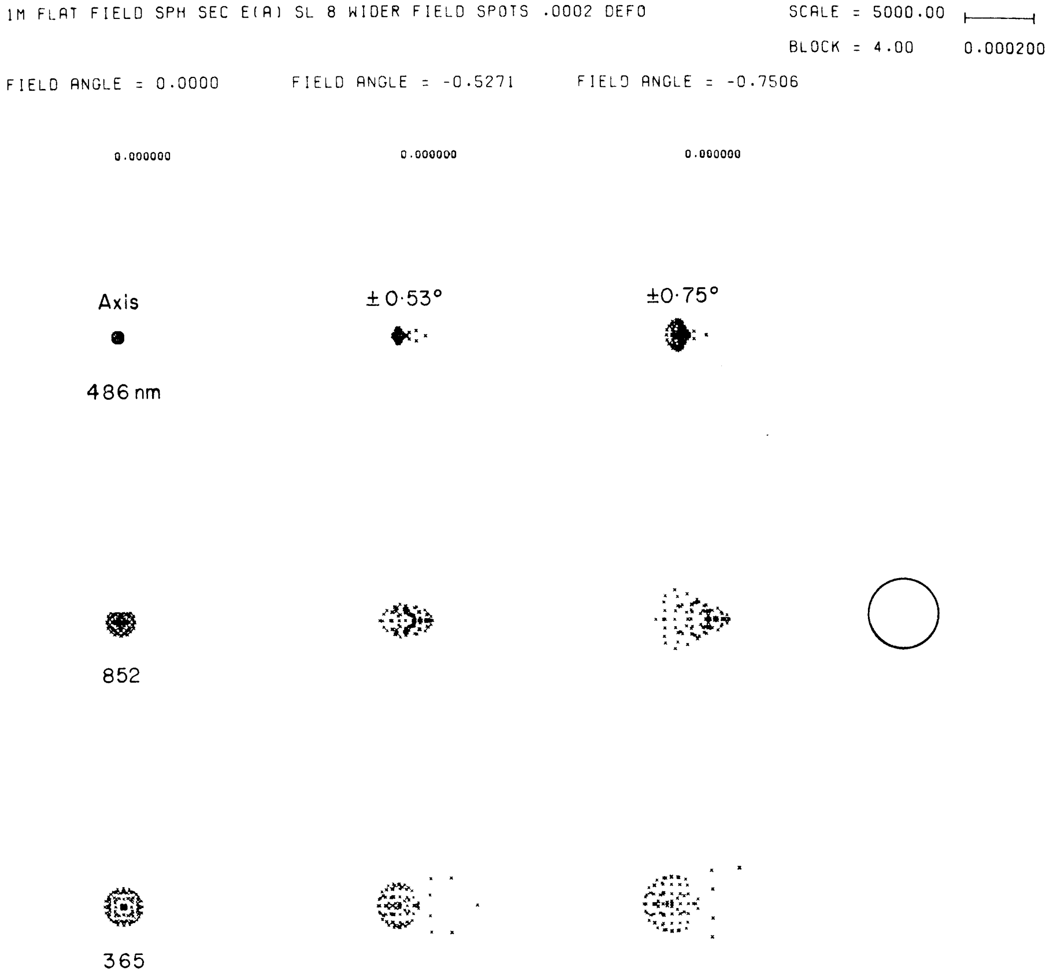

FIG. 1. *Spot diagrams for the design of Table I. The three columns relate to imagery on axis, and at obliquities of* 0·53° *and* 0·75°, *the three rows to light of wavelengths* 486, 852 *and* 365 *nm. The scale is shown by a circle of* $\frac{1}{2}$ *arcsec diameter.*

2. DESIGN CONSIDERATIONS

The design of systems with doublet lens correctors is governed by the following considerations. The doublet is preferably substantially afocal, so that achromatism does not require the use of glasses of differing dispersions, which give rise to secondary spectrum aberrations. The components of the doublet should be thin, to introduce aberrations thin lenses must have power, and for the doublet to be afocal the two lenses must be of equal positive and negative powers. A system of a thin positive and a negative thin lens can only be corrected for chromatic difference of focus and magnification if they are located close together. The basic function of the doublet is to introduce a large comatic aberration, of a size to annul that of the mirror pair, together with a small appropriate astigmatism; first order aberration theory shows that a close doublet meeting these conditions necessarily introduces spherical aberration, and the purpose of modifying the Cassegrain mirror system is to correct this; if this is done by modifying the secondary mirror shape, it requires a mirror more nearly spherical than the true Cassegrain one.

A close afocal doublet giving the required primary coma and astigmatism can be designed for a range of positions between the mirror pair and the focal plane.

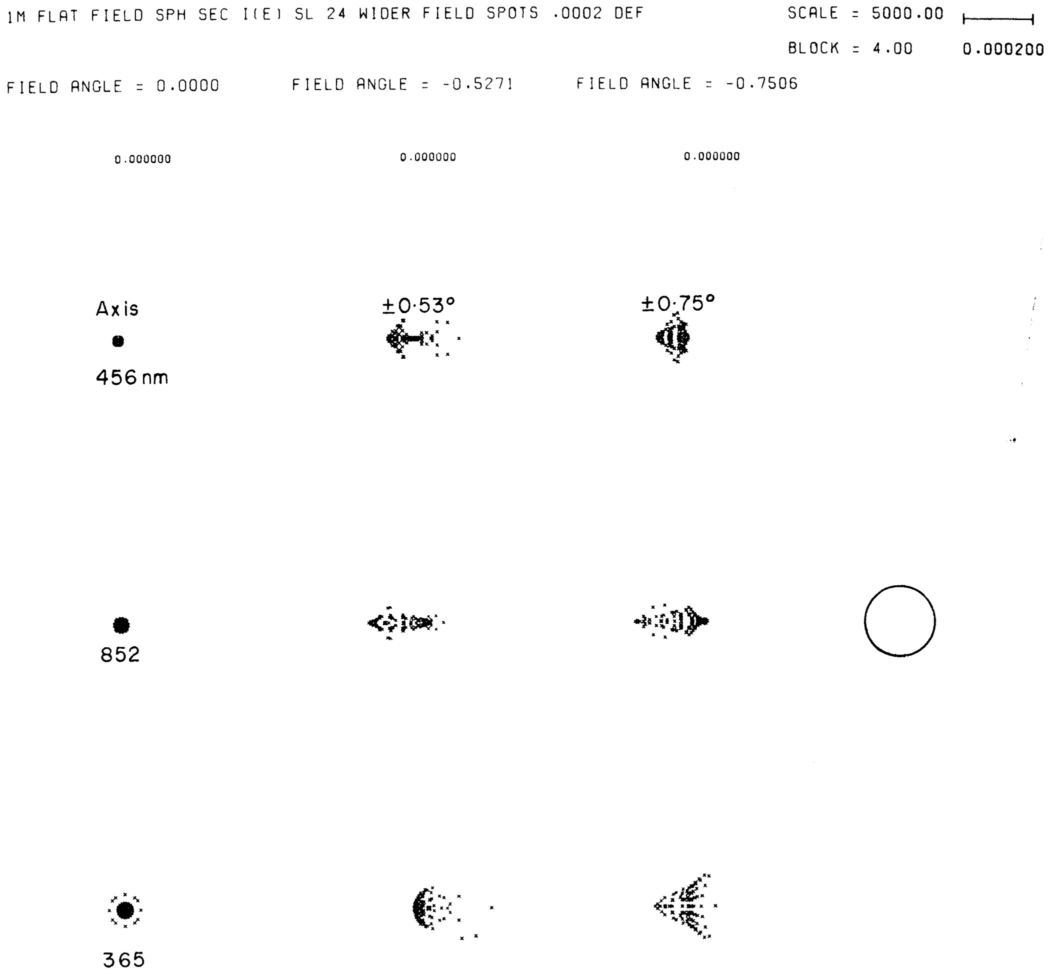

FIG. 2. *Spot diagrams for the design of Table II. The three columns relate to imagery on axis, and at obliquities of* 0·53° *and* 0·75°, *the three rows to light of wavelengths* 486, 852 *and* 365 *nm. The scale is shown by a circle of* ½ *arcsec diameter.*

For a doublet position closer to the focus, the spherical aberration it introduces is smaller (requiring less change to the secondary mirror), the surface curvatures required become deeper, with a consequent increase in higher order aberrations at larger field angles, and the size of the doublet lenses, for a given field angle, becomes smaller. For a large telescope, it is necessary to restrict the size of the corrector lens to a small fraction of the prime mirror diameter, both for reasons of convenience in use, and practicability of manufacture; and since large telescopes are required to cover only moderate field angles, a doublet position will be chosen relatively close to the focus. For such designs, aberration correction requires a secondary mirror with an asphericity typically about 0·9 of that of the true Cassegrain secondary.

For a smaller telescope, for example of about 1-m aperture, required to cover a wider field angle, aberration correction requires a doublet relatively further from the focus, of a size relative to the prime mirror that would be impracticable on a very large telescope; the doublet so located introduces relatively large spherical aberration, requiring a greater change in the secondary mirror shape. It emerges that, for an appropriate doublet position, spherical aberration correction requires that the secondary mirror assumes an exactly spherical form; this has

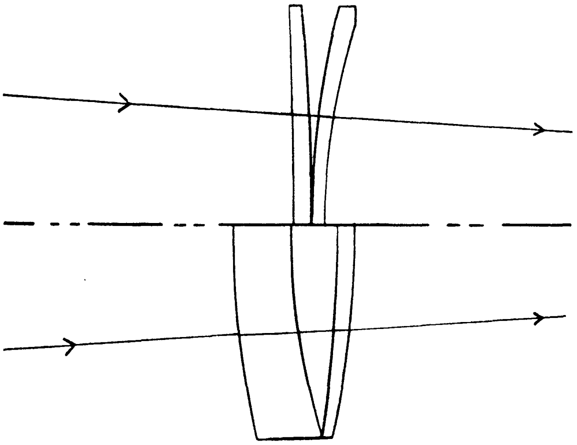

FIG. 3. *Section drawings of two doublet lens designs; above, that corresponding to the data of Table I; below, to the data of Table II.*

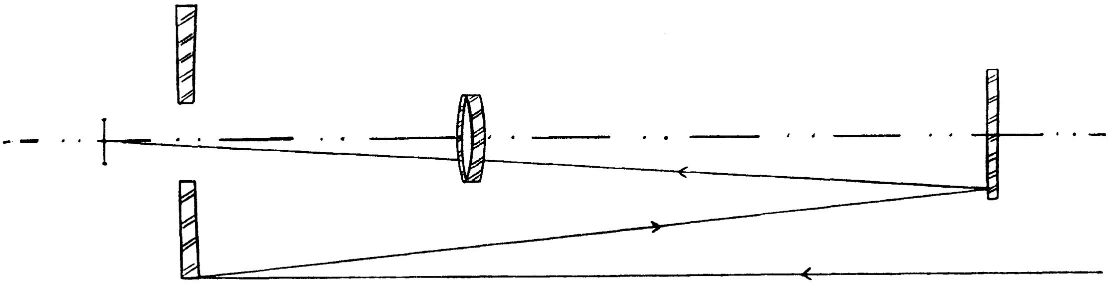

FIG. 4. *Section drawing of the optical system described in Table II.*

some advantages in the cost of making and testing of the mirror, and also for the centring requirements of the mirror pair.

3. TWO EXAMPLES AND THEIR PERFORMANCE

The level of optical performance attainable for such systems is here exemplified by two designs, for a 1-m *f*/4·85 prime paraboloid, giving an angular field of 1·5° diameter at a relative aperture of about *f*/8. In the first design (Table I) the doublet lens has its component of positive power nearer to the prime mirror, in the second example (Table II) the components are in the reverse order. Spot diagrams of the two systems are given in Figs 1 and 2, in each case for imagery on axis, and at obliquities of 0·53° and 0·75°, for light of wavelengths 486, 852 and 365 nm, the scale being indicated by a circle of 0·5 arcsec diameter. The diagrams derive from a square array of 81 rays in the entrance pupil, of which 12 lie on the pupil periphery; no account has been taken of central obstruction and there is no vignetting of oblique imagery. The magnitude of the aberrations is rather similar in the two cases, though the structure is different. In each case, the geometrical image spread is substantially less than 0·5 arcsec over the central part of the field, and remains within this limit over the whole 1·5° field for most of the spectral range. Fig. 3 shows section drawings of the two correctors, the first design in the upper half and the second below. Fig. 4 shows a section drawing of the complete optical system described in Table II.

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